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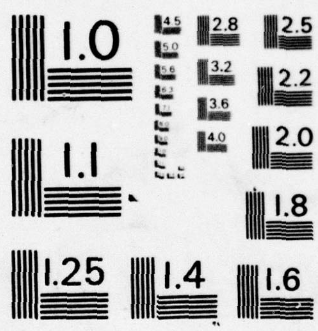

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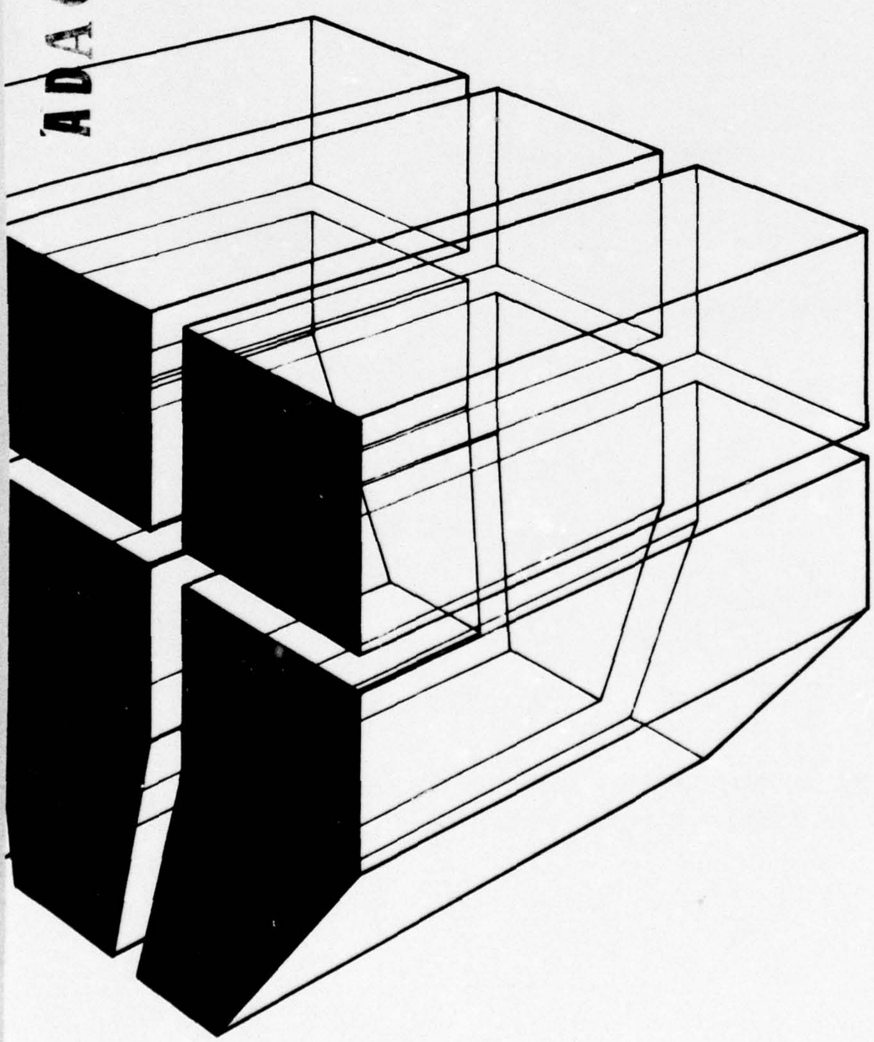
TECHNICAL REPORT M-197
December 1976
Weldability of Construction Materials

DETERMINATION OF ARC VOLTAGE, AMPERAGE, AND TRAVEL SPEED LIMITS BY BEAD-ON-PLATE WELDING



by
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This report presents the results of bead-on-plate tests to define limits for voltage, amperage, and travel speed. The work was divided into two sections: shielded metal-arc welding (SMAW) and gas metal-arc welding (GMAW). The limits for voltage and travel speed were determined for SMAW electrodes based on limits previously determined by the American Welding Society (Specification A5.1-69). Voltage and amperage limits for GMAW electrodes were determined based on types of metal transfer; travel speed limits were based on bead appearance and shape. The results of this research are not final; over LB

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further work on butt welds will refine the limits. The final results will be used to prepare recommended changes to appropriate guide specifications and technical manuals.

FOREWORD

This work was conducted by the U.S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A762731AT41, "Materials Research and Development for Military Construction"; Task T7, "Application Engineering"; Work Unit 007, "Weldability of Construction Materials." The applicable QCR number is 1.06.004.

The OCE technical monitor for this project is Mr. I. A. Schwartz, DAEN-MCE-D.

CERL personnel concerned with the investigation were Mr. R. A. Weber and Mr. F. Kisters of the Metallurgy Branch (MSM), Materials and Science Division (MS). Mr. C. E. Jackson, professor in the Department of Welding Engineering at Ohio State University, acted as a consultant for this project.

The Chief of MSM is Dr. A. Kumar and the Chief of MS is Dr. G. R. Williamson. COL J. E. Hays is Commander and Director of CERL and Dr. L. R. Shaffer is Technical Director.

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DETERMINATION OF ARC VOLTAGE, AMPERAGE, AND TRAVEL SPEED LIMITS BY BEAD-ON-PLATE WELDING

1 INTRODUCTION

Background

Shielded metal-arc welding (SMAW) and gas metal-arc welding (GMAW) are the predominant forms of electric arc welding used today. SMAW is used about twice as often as GMAW for both field and shop fabrication. Electrode technology has been improved to the point where many types of electrodes are now available to respond to a wide variety of welding problems. The American Welding Society (AWS) has developed a classification system for steel welding electrodes based on some of the electrodes' characteristics. The SMAW classification codes are made up of an E and four or five numbers (EXXYZ). The E designates that the material is an electrode. The first two numbers, XX, give the minimum deposited weld metal tensile strength; that is, an electrode with an E60YZ classification would have a minimum deposited tensile strength of 60,000 psi (4.13 MPa). This tensile strength designation can be 60, 70, 80, 100, or 110. The number represented by Y–either 1 or 2–designates the welding position in which the electrode can be used. A 1 means that the electrode can be used in all positions–flat, horizontal, vertical, and overhead; a 2 indicates that usage is limited to flat or horizontal fillet welds. The last term in the classification, Z, can be any number from 0 through 8. These numbers indicate major coating constituents and welding current limitations, as shown in Table 1.

The classification system for GMAW electrodes is somewhat simpler. The first three or four characters, EXX or EXXX, have the same meaning as in the SMAW code; the only difference is that the tensile strength designations for GMAW wires range from 70 to 110. The next digit is either S or U. An S means that the electrode has no coating and is a solid wire. A U means that the solid wire has an emissive coating. The final digit can be any number from 1 through 6 or the letter G. The numbers refer to different chemical compositions, in particular carbon and silicon contents. The G represents a general classification which has no chemistry restrictions except that nickel, chromium, molybdenum, or vanadium cannot be intentionally added.[1]

The choice of electrode is governed by the strength level of the plate being welded, the welding process, and the position of the weld. The quality of the welds resulting from the large number of possible electrode/steel combinations is related to the welding process variables–current, voltage, and travel speed. To determine the relationship and to optimize weld quality, a three-phase study was undertaken to establish arc voltage, current, and travel speed limits. The first phase, reported here, involved establishing limits using bead-on-plate welds. The second phase will define the limits based on work with butt welds, and the final phase will determine the crack sensitivity of weldments deposited using the limits defined in the first two phases.

Objective

The objective of the first phase of this study was to determine the extreme limits of arc voltage, current, and travel speed for steels used by the Corps of Engineers. These limits were to be established by visual inspection and macroexamination of bead-on-plate welds produced with differing arc variables.

Materials

Table 2 identifies the plate steels (by American Society for Testing and Materials [ASTM] code numbers) and the electrodes (by AWS code numbers) used in this investigation. Selection of the electrode types to be used within each plate material was based on the AWS *Structural Welding Code.*[2]

The number of plates and electrode types used was limited by their availability. Most plate materials were available in mill run quantities only (approximately 20 tons [18.1 metric tons]) and were not purchased because of cost and storage problems. A similar situation was encountered with the electrodes.

Two types of shielding gases were used with GMAW: (1) a mixture of argon and oxygen and (2) carbon dioxide. Tests with the E70S-2 and E70S-3 electrodes were shielded with both of the gases, while E70S-4 and E70S-6 were shielded with carbon dioxide only and the E110S electrode was shielded with argon and 2 percent oxygen only.

Approach

All plate material was cut to approximately 12 in. x 18 in. (0.3 m x 0.5 m) using an oxyacetylene cutting

[1] "Specification for Low-Alloy Steel Covered Arc-Welding Electrodes, " A5.5-69 (American Welding Society, 1969).

[2] "Specifications for Mild Steel Electrodes for Gas Metal-Arc Welding," A5.18-69, *Structural Welding Code*, D1.1-75 (American Welding Society, 1969).

apparatus. The surface to be welded was sandblasted and wire-brushed to remove surface oxides and paints.

Welding was performed with manual SMAW and fully automatic GMAW systems using reversed polarity direct current. Individual weld beads were deposited with preset voltage, amperage, and travel speed. Each variable was changed to find the maximum and minimum tolerable limits. Table 3 contains the parameters for each electrode and plate material.

The deposited beads were visually inspected for bead contour and shape and then sectioned for macrospecimen examination. The macrospecimens were polished and etched with 5 percent nital and examined for penetration, reinforcement, undercut, and porosity. From all these observations, limits of voltage, amperage, and travel speed were determined.

2 RESULTS AND DISCUSSION

Shielded Metal-Arc Welds

The AWS specification A5.1-69[3] amperage limits for SMAW electrodes, which are based on wire diameter and coating compositon, were used in this study in establishing the voltage and travel speed limitations. The amperage limits are noted below for each electrode. Table 4 presents the voltage limits established for the SMAW electrodes. Voltage, which is directly related to the arc length, affects both bead width and shielding characteristics, i.e. a long arc length (high voltage) produces a wide bead and could produce porosity in the weld by allowing the aspiration of air into the arc atmosphere.

Figures 1 through 7 are graphs of travel speed versus current for the individual SMAW electrodes; the dashed lines are the travel speed limits at various current levels. These limits were determined by bead shape and amount of undercut. Undercutting is caused by a combination of factors, but primarily by too high a rate of speed for a given current level. A large area is melted and drawn into the center of the bead and the arc passes by too quickly to allow a sufficient weld metal deposit in the welded area. Undercut results. Each electrode is discussed separately below.

E6010

The E6010 electrode is a high cellulose sodium electrode that has many uses in welded fabrication. It produces a forceful, spray-type arc which gives deep penetration. The slag cover on the weld bead is thin and easily removed.

AWS specification A5.1-69 gives an amperage range of 75 to 125 A for this electrode. The voltage was varied from 28 to 34 V and the travel speed used ranged from 6 to 21.7 in./min (15.2 to 55.1 cm/min).

The lower limit for voltage was determined to be 28 V due to handling characteristics and the tendency to short circuit with lower voltages. The upper limit of 32 V was based on visual inspection of the external surface and a macrospecimen, and on the usability of the electrode with long arc lengths. Figure 1 shows the limits for travel speed determined by bead shape and amount of undercut.

E6011

The E6011 electrode is quite similar to the E6010 electrode in arc characteristics, except that sodium is used in place of potassium, which enables the electrode to be used with alternating as well as direct current. The current range for this electrode is also 75 to 125 A. At the low end of the current range, the penetration was minimal, and overall the penetration was less than that of the E6010 electrode.

The voltage was varied between 28 and 35 V. Based on the same criteria used for the E6010 electrode, the voltage range was determined to be 28 to 32 V. The travel speed was varied between 6 and 11.4 in./min (15.2 and 29.0 cm/min). Figure 2 shows the limits of travel speed determined by bead shape and amount of undercut.

E6013

The E6013 electrode was originally designed for light gage sheet metal, although larger electrode diameters are used for single-pass, high-speed horizontal fillet welds. The electrode can be used for welding sheet metal in the vertical-down position.

The current range for this electrode is 130 to 150 A; the voltage used ranged from 22 to 27 V. The voltage limits determined for the E6013 electrode are 22 and 26 V. The travel speed was varied for 7.2 and 17.8 in./min (9.7 to 45.2 cm/min). Figure 3 shows the limits on travel speed for this electrode.

E7018

The E7018 electrode has a smooth, quiet arc with small amounts of spatter and low penetration. Very high

[3] "Specification for Mild Steel Covered Arc-Welding Electrodes," A5.1-69, *Structural Welding Code*, D1.1-75 (American Welding Society, 1969).

welding speeds can be used with this electrode. The coating contains as much as 25 to 40 percent iron powder. This low-hydrogen electrode is used where other types of electrodes could cause underbead cracking, which is usually attributed to hydrogen pick-up from the arc atmosphere.

The amperage range for this electrode is 115 to 165 A. The test welds were made with voltages between 25 and 38 V. Based on bead shape, porosity content, and usability, the limits on voltage were determined to be 25 and 28 V. The travel speed was varied between 6.3 and 22.9 in./min (16.0 and 58.2 cm/min). Figure 4 shows the travel speed limits for the E7018 electrode.

Weld beads produced with the E7018 electrode on the different types of steel plate showed no differences that were related to the plate. Therefore, all welds made with the E7018 electrode were grouped together to determine the tolerable limits of voltage, current, and travel speed, as were the welds produced with the E7024 electrode, discussed next.

E7024

The E7024 electrode's heavy coating, which contains high percentages of iron powder, makes up about 50 percent of the total electrode weight. E7024, which is manufactured specifically for flat position and horizontal fillet welding, has a smooth, quiet arc with very small amounts of spatter. This electrode generally has low penetration and can be used with high lineal speed.

The current range for this electrode is 115 to 165 A. Weld beads were produced with voltages from 26 to 42 V and travel speeds from 7 to 26.7 in./min (17.8 to 67.8 cm/min). The usable range for voltage was determined to be 26 to 32 V. Figure 5 shows the travel speed range for this electrode.

E8018

The E8018 electrode, which is used with high-strength steel, is a low-hydrogen electrode with arc characteristics similar to the E7018 electrode. The electrode provides shallow penetration with a smooth, quiet arc and small amounts of spatter.

The amperage range for this electrode is 150 to 220 A. The voltage used for this electrode ranged from 22 to 36 V, and the travel speed ranged from 8 to 20 in./min (20.3 to 50.8 cm/min). The usable voltage range was determined to be 22 to 28 V. Figure 6 shows the travel speed at various current levels.

E11018

The E11018 electrode is also a low-hydrogen electrode that is used for high-strength, low alloy steels. The arc characteristics are similar to the E7018 and E8018 electrodes.

The current range for this electrode is 115 to 165 A. The voltage used was 25 to 35 V, and the travel speed ranged from 6.3 to 17.8 in./min (16.0 to 45.2 cm/min). The voltage range for this electrode was determined to be 25 to 30 V; above 30 V, porosity and spatter became problems, and below 25 V, usability dropped off because of short circuiting problems. Figure 7 shows the travel speed limits for the E11018 electrode.

Gas Metal-Arc Welds

The travel speed, voltage, and current limits for the GMAW electrodes were not as clearly delineated as those for the SMAW electrodes. Arc voltage and current level combinations can be adjusted to give several types of metal transfer. With the use of argon plus 2 to 5 percent oxygen addition, transfer can be by large droplets (globular) with low power levels or by a fine spray with high power levels. There is a clear-cut transition to spray transfer, which is the method normally used with argon-oxygen shielded GMAW.

With carbon dioxide shield gas, three types of transfer—short circuit, repelled, and projected—can be obtained, depending on the levels of current and voltage. The short circuiting transfer method, which was developed for thin materials and welding in the vertical and overhead positions, involves transfer of weld metal from the electrode tip by repetitive short circuits through contact of the molten electrode and the work piece. The wire diameters recommended for short circuiting welding are 0.030 in. (0.8 mm) or 0.045 in. (1.1 mm). The 0.062-in. diameter (1.6 cm) wire used in this investigation is not normally used in short circuiting transfer because of the higher currents required to melt this size of electrode. Higher currents and voltage cause formation of droplets at the end of the electrode. As these droplets enlarge, they begin to detach from the electrode. Forces in the center of the arc give the drop an initial acceleration that repels it from the weld pool. With further increased current levels, the electromagnetic forces pinch the drop off and project it toward the weld pool. The projected transfer mode is most frequently used because it gives better penetration and less spatter than the repelled transfer mode.

Figures 8 through 14 are graphs of voltage versus current levels for the GMAW electrodes used in this

study. The lines on these graphs represent the boundaries between types of metal transfer. In Figure 10, the two points at the lower left are from arcs that exhibited short circuiting characteristics but were very erratic and had minimal usability; the settings used in these arcs are not recommended when using shield gas of argon with 2 percent oxygen addition. The spray transfer region was established for the three electrodes that can be used with argon-oxygen shield gas (Figures 8, 10, and 14).

The four electrodes shielded with carbon dioxide gas–E70S-2, E70S-3, E70S-4, and E70S-6–all exhibited the three types of weld metal transfer. Figures 9, 11, 12, and 13 show the limits of the three transfer modes.

The travel speed for each electrode ranged from 5 to 35 in./min (12.7 to 88.9 cm/min). With the exception of E70S-2 shielded with argon with 2 percent oxygen addition and A 36 steel, no significant undercutting was present at the toe of the weld. Further examination of the A 36 welds showed that the problem of undercut was due to a cast in the weld wire which forced the arc to one side, leaving an undercut toe on the other side. The usable range of travel speed was 10 to 35 in./min (25.4 to 88.9 cm/min). Below 10 in./min (25.4 cm/min) the weld crown became excessively high, exceeding the AWS's 1/8-in. (3.2 mm) limit (AWS D1.1-75). A few isolated weld beads other than those deposited at the slow travel speeds exceeded the maximum. These were attributed to short arc lengths and high current levels that did not allow the weld metal to spread out, thus resulting in tall, narrow weld beads. Further work is required to better characterize the travel speed limits for the GMAW process. These limits should be better defined by the butt weld stage of this study, during which mechanical property tests will be conducted to further refine the tolerable limits of weld variables.

Table 1

Coatings and Current Designation

Z	Coating Types	Current Types
0	High cellulose sodium*	dc, reversed polarity
1	High cellulose potassium	ac or dc, reversed polarity
2	High titania sodium	ac or dc, straight polarity
3	High titania potassium	ac or dc, either polarity
4	Iron powder titania	ac or dc, either polarity
5	Low hydrogen sodium	dc, reversed polarity
6	Low hydrogen potassium	ac or dc, reversed polarity
7	Iron powder, iron oxide	ac or dc, either polarity**
8	Iron powder, low hydrogen	ac or dc, reversed polarity

* Except when preceded by a 2; in that case it is high iron oxide, ac or dc, either polarity.

** Reversed polarity is not recommended for horizontal fillets.

3 CONCLUSIONS

The travel speed and voltage limitations for SMAW electrodes were established using the American Welding Society's current limits. The travel speed was found to be current-dependent; that is, at low current levels slower travel speeds are required, while at high current levels faster travel speeds are required.

Current and voltage limits for GMAW electrodes were determined based on the most frequently used transfer modes through the arc. Travel speeds between 10 and 35 in./min (25.4 and 88.9 cm/min) were found to be acceptable for GMAW electrodes, except in special cases of low voltages and high currents, where the weld beads were narrow and high.

These conclusions, however, are not final. Further refinement of the limits of voltage, current, and travel speed is anticipated when butt joints are studied in the second phase of this study. The third phase will determine the effect of weldments deposited using the defined limits on crack sensitivity. The final results will be used to revise and update Technical Manual TM 5-805-7[4] and to propose changes to guide specifications such as CE 260.02.[5]

[4] *Welding; Design, Procedures and Inspection*, TM-5-805-7 (Department of the Army, 1968).

[5] *Welding, Structural for Critical Applications*, CE 260.02 (Office of the Chief of Engineers, June 1968).

Table 2

Materials Used in Study

Plate Material (ASTM No.)	Electrodes (AWS No.) GMAW	SMAW
A 36	E70S-2, E70S-3 E70S-4, E70S-6	E6010, E6011 E6013, E7018 E7024
A 242	E70S-2, E70S-3 E70S-4, E70S-6	E7018, E7024
A 441	E70S-2, E70S-3 E70S-4, E70S-6	E7018, E7024
A 514	E110S	E11018
A 527	E70S-2, E70S-3 E70S-4, E70S-6	E7018, E7024
A 588	E70S-2, E70S-3 E70S-4, E70S-6	E7018, E7024
A 710	–	E8018

Table 3

Welding Parameters of Bead-on-Plate Welds

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
E6010 (1/8-in. [3.2 mm] diameter)			
A 36	75	28	7.5 (19.1)
	75	32	7.7 (19.6)
	75	28	6.0 (15.2)
	100	29	8.3 (21.1)
	100	29	14.1 (35.8)
	100	34	9.8 (24.9)
	125	30	11.7 (29.7)
	125	28	21.7 (55.1)
	125	38	13.3 (33.8)
E6011 (1/8-in. [3.2 mm] diameter)			
A 36	75	28	9.6 (24.4)
	75	34	8.7 (22.1)
	75	30	8.0 (20.3)
	75	30	6.0 (15.2)
	100	28	11.4 (29.0)
	100	28	8.0 (20.3)
	100	35	10.0 (25.4)
	125	30	8.2 (20.8)
	125	30	13.7 (34.8)
	125	28	7.2 (18.3)
E6013 (1/8-in. [3.2 mm] diameter)			
A 36	130	22	8.3 (21.1)
	130	23	16.0 (40.6)
	130	27	9.6 (24.4)
	150	26	10.0 (25.4)
	150	27	17.8 (45.2)
	150	22	7.2 (18.3)
	150	24	9.4 (23.9)
E7018 (1/8-in. [3.2 mm] diameter)			
A 36	115	25	8.7 (22.1)
	115	25	15.0 (38.1)
	115	25	8.0 (20.3)
	140	26	10.2 (25.9)
	140	25	20.0 (50.8)
	140	26	8.3 (21.1)
	165	27	12.0 (30.5)
	165	28	15.5 (39.4)
	165	28	7.5 (19.1)
A 242	115	26	6.5 (16.5)
	115	25	8.4 (21.3)
	115	25	12.0 (30.5)
	115	25	16.6 (42.2)
	140	26	8.0 (20.3)
	140	27	12.0 (30.5)
	140	26	16.0 (40.6)
	165	28	8.0 (20.3)
	165	27	12.0 (30.5)
	165	27	17.0 (43.4)
A 441	115	25	6.3 (16.0)
	115	38	6.4 (16.3)
	115	28	6.7 (17.0)
	115	26	8.9 (22.6)
	115	25	12.3 (31.2)
	115	24	15.5 (39.4)
	115	25	17.1 (43.4)
	135	26	6.7 (17.0)
	135	32	7.0 (17.8)
	140	26	12.0 (30.5)
	140	26	8.0 (20.3)
	140	26	18.5 (47.0)
	150	26	7.5 (19.1)
	150	35	8.1 (20.6)
	150	32	8.5 (21.6)
	165	27	8.2 (20.8)
	165	36	8.7 (22.1)
	165	33	8.6 (21.8)
	165	26	10.4 (26.4)
	165	26	16.6 (42.2)
	165	26	22.9 (58.2)
A 572	115	26	8.7 (22.1)
	115	25	16.6 (42.2)
	115	26	10.4 (26.4)
	140	26	8.0 (20.3)
	140	26	20.0 (50.8)
	140	26	13.0 (33.0)
	165	29	12.0 (30.5)
	165	28	16.0 (40.6)
	165	27	8.7 (22.1)
A 588	115	26	8.0 (20.3)
	115	25	14.6 (37.1)
	115	26	9.8 (24.9)
	140	26	8.0 (20.3)
	140	26	18.5 (47.0)
	140	27	10.7 (27.2)
	165	28	8.5 (21.6)
	165	30	20.0 (50.8)
	165	32	9.8 (22.9)
E7024 (1/8-in. [3.2 mm] diameter)			
A 36	140	29	12.3 (31.2)
	140	30	21.8 (55.4)
	140	30	7.7 (19.6)
	170	31	10.7 (27.2)
	170	32	20.0 (50.8)
	170	31	7.0 (17.8)
	190	34	12.6 (32.0)
	190	34	20.9 (53.1)
	190	32	7.8 (19.8)
A 242	140	26	22.9 (58.2)
	140	27	12.0 (30.5)
	140	27	8.0 (20.3)
	170	30	19.2 (48.8)
	170	30	12.0 (30.5)
	170	30	8.3 (21.1)
	190	32	20.9 (53.1)
	190	32	12.0 (30.5)
	190	32	8.0 (20.3)

Table 3 (cont'd)

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
A 441	140	26	21.8 (55.4)
	140	28	12.0 (30.5)
	140	28	8.0 (20.3)
	140	32	8.3 (21.1)
	140	40	8.1 (20.6)
	170	31	9.4 (23.9)
	170	40	11.2 (28.4)
	190	32	11.2 (28.4)
	190	42	11.2 (28.4)
	190	33	22.9 (58.2)
	190	33	16.0 (40.6)
A 572	140	28	10.4 (26.4)
	140	30	22.9 (58.2)
	140	29	8.0 (20.3)
	170	29	9.8 (24.9)
	170	31	20.9 (53.1)
	170	30	8.0 (20.3)
	190	31	10.9 (27.7)
	190	33	24.0 (61.0)
	190	32	10.4 (26.4)
A 588	140	28	10.9 (27.7)
	140	27	25.3 (64.3)
	140	28	7.7 (19.6)
	170	32	15.0 (38.1)
	170	31	26.7 (67.8)
	170	31	7.8 (19.8)
	190	33	12.6 (32.0)
	190	33	24.0 (61.0)
	190	33	7.8 (19.8)
E8018 (5/32-in. [4.0 mm] diameter)			
A 710	150	22	13.0 (33.0)
	150	27	13.7 (34.8)
	150	25	8.0 (20.3)
	185	26	12.0 (30.5)
	185	26	19.5 (49.5)
	185	30	10.4 (26.4)
	185	26	8.0 (20.3)
	220	28	12.0 (30.5)
	220	36	12.0 (30.5)
	220	30	20.0 (50.8)
	220	29	8.2 (20.8)
E11018 (1/8-in. [3.2 mm] diameter)			
A 514	115	25	8.0 (20.3)
	115	32	8.0 (20.3)
	115	27	8.0 (20.3)
	115	25	11.4 (29.0)
	115	25	6.3 (16.0)
	115	25	17.1 (43.4)
	140	26	17.1 (43.4)
	140	25	12.0 (30.5)
	140	25	7.5 (19.1)
	140	28	8.4 (21.3)
	140	34	10.2 (25.9)
	165	27	10.9 (27.7)
	165	35	9.4 (23.9)
	165	30	10.9 (27.7)
	165	26	17.8 (45.2)
	165	26	10.0 (25.4)
	165	26	8.5 (12.7)
E70S-2 (1/16-in. [1.5 mm] diameter) (argon with 2 percent oxygen addition)			
A 36	360	25	15 (38.1)
	350	25	15 (38.1)
	300	26	15 (38.1)
	400	23	15 (38.1)
	370	20	15 (38.1)
	315	22	15 (38.1)
	295	22	15 (38.1)
	270	23	15 (38.1)
	260	25	15 (38.1)
	200	20	15 (38.1)
	250	20	15 (38.1)
	275	19	15 (38.1)
	310	18	15 (38.1)
	360	33	15 (38.1)
	430	32	15 (38.1)
	470	31	15 (38.1)
	370	24	30 (76.2)
	380	24	25 (63.5)
	350	25	20 (50.8)
	350	25	10 (25.4)
	305	25	5 (12.7)
	320	18	10 (25.4)
	310	18	20 (50.8)
	315	18	25 (63.5)
	320	18	30 (76.2)
	500	29	30 (76.2)
A 242	365	25	35 (88.9)
	365	25	25 (63.5)
	390	25	15 (38.1)
	390	25	10 (25.4)
A 441	360	25	35 (88.9)
	360	25	35 (88 9)
	385	25	15 (38.1)
	385	25	10 (25.4)
A 572	365	25	15 (38.1)
	380	25	25 (63.5)
	380	25	35 (88.9)
A 588	390	25	35 (88.9)
	390	25	25 (63.5)
	390	25	15 (38.1)
	390	25	10 (25.4)
E70S-2 (1/16-in. [1.5 mm] diameter) (carbon dioxide)			
A 36	300	35	10 (25.4)
	350	34	10 (25.4)
	390	34	10 (25.4)
	430	33	15 (38.1)
	430	32	15 (38.1)
	450	32	15 (38.1)

Table 3 (cont'd)

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
	380	25	15 (38.1)
	365	25	15 (38.1)
	360	27	15 (38.1)
	345	26	15 (38.1)
	280	27	15 (38.1)
	330	20	15 (38.1)
	280	20	15 (38.1)
	210	22	15 (38.1)
	170	22	15 (38.1)
	380	26	35 (88.9)
	380	25	30 (76.2)
	380	26	5 (12.7)
A 242	375	25	35 (88.9)
	375	25	25 (63.5)
	360	26	15 (38.1)
	360	26	10 (25.4)
A 441	360	26	35 (88.9)
	360	26	25 (63.5)
	370	25	15 (38.1)
	370	25	10 (25.4)
A 572	370	25	25 (88.9)
	365	25	25 (63.5)
	360	25	15 (38.1)
A 588	360	26	35 (88.9)
	360	26	25 (63.5)
	360	26	15 (38.1)
	360	26	10 (25.4)

E70S-3 (1/16-in. [1.5 mm] diameter) (argon with 2 percent oxygen addition)

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
A 36	400	28	15 (38.1)
	445	27	15 (38.1)
	465	28	15 (38.1)
	400	20	15 (38.1)
	370	20	15 (38.1)
	350	21	15 (38.1)
	355	21	15 (38.1)
	300	22	15 (38.1)
	275	23	15 (38.1)
	150	18	15 (38.1)
	230	24	15 (38.1)
	200	17	15 (38.1)
	250	16	15 (38.1)
	340	16	15 (38.1)
	280	16	15 (38.1)
	285	16	25 (63.5)
	280	16	30 (76.2)
	280	16	20 (50.8)
	250	17	10 (25.4)
	410	27	10 (25.4)
	410	27	20 (50.8)
	410	27	25 (63.5)
	390	28	30 (76.2)
	415	27	5 (12.7)
	410	27	35 (88.9)

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
A 242	380	25	35 (88.9)
	380	25	25 (63.5)
	375	25	15 (38.1)
	375	25	10 (25.4)
A 441	380	25	35 (88.9)
	380	25	25 (63.5)
	370	25	15 (38.1)
	370	25	10 (25.4)
	370	25	35 (88.9)
A 572	370	25	25 (63.5)
	360	25	15 (38.1)
A 588	370	26	35 (88.9)
	370	26	25 (63.5)
	375	25	15 (38.1)
	375	25	10 (25.4)

E70S-3 (1/16-in. [1.5 mm] diameter) (carbon dioxide)

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
A 36	180	22	10 (25.4)
	230	21	15 (38.1)
	270	20	15 (38.1)
	310	19	15 (38.1)
	300	27	15 (38.1)
	325	26	15 (38.1)
	350	26	15 (38.1)
	380	26	15 (38.1)
	400	25	15 (38.1)
	420	24	15 (38.1)
	365	33	15 (38.1)
	415	32	15 (38.1)
	440	32	15 (38.1)
	480	31	15 (38.1)
	365	26	35 (88.9)
	395	25	35 (88.9)
	385	25	25 (63.5)
	385	25	10 (25.4)
A 242	370	26	35 (88.9)
	370	26	25 (63.5)
	350	26	15 (38.1)
	350	26	10 (25.4)
A 441	350	26	35 (88.9)
	350	26	25 (63.5)
	360	26	15 (38.1)
	360	26	10 (25.4)
A 572	350	26	35 (88.9)
	350	26	25 (63.5)
	350	26	15 (38.1)
	340	26	10 (25.4)
A 588	370	26	35 (88.9)
	370	26	25 (63.5)
	360	26	15 (38.1)
	360	26	10 (25.4)

Table 3 (cont'd)

Plate Material (ASTM No.)	Current, A	Voltage, V	Travel Speed, in./min (cm/min)
E70S-4 (1/16-in. [1.5 mm] diameter) (carbon dioxide)			
A 36	140	22	20 (50.8)
	230	21	15 (38.1)
	280	20	15 (38.1)
	360	19	15 (38.1)
	220	29	15 (38.1)
	300	28	15 (38.1)
	350	26	15 (38.1)
	370	25	15 (38.1)
	300	34	15 (38.1)
	375	33	15 (38.1)
	420	32	15 (38.1)
	450	32	15 (38.1)
	360	26	35 (88.9)
	350	26	25 (63.5)
	335	26	10 (25.4)
A 242	360	26	35 (88.9)
	360	26	25 (63.5)
	360	26	15 (38.1)
	350	26	10 (25.4)
A 441	360	26	35 (88.9)
	360	26	25 (63.5)
	360	26	15 (38.1)
	350	26	10 (25.4)
A 572	340	26	35 (88.9)
	340	26	25 (63.5)
	330	26	15 (38.1)
A 588	360	26	35 (88.9)
	360	26	25 (63.5)
	360	26	15 (38.1)
	360	26	10 (25.4)
E70S-6 (1/16-in. [1.5 mm] diameter) (carbon dioxide)			
A 36	340	34	15 (38.1)
	440	32	15 (38.1)
	440	32	15 (38.1)
	400	25	15 (38.1)
	360	26	15 (38.1)
	340	26	15 (38.1)
	280	27	15 (38.1)
	315	19	15 (38.1)
	270	20	15 (38.1)
	220	21	15 (38.1)
	140	22	15 (38.1)
	340	26	35 (88.9)
	340	26	25 (63.5)
	340	26	5 (12.7)
A 242	340	26	35 (88.9)
	340	26	25 (63.5)
	320	26	15 (38.1)
	320	26	10 (25.4)
A 441	340	26	35 (88.9)
	340	26	25 (63.5)
	365	26	15 (38.1)
	365	26	10 (25.4)
A 572	340	26	35 (88.9)
	350	26	25 (63.5)
	360	26	15 (38.1)
	350	26	10 (25.4)
A 588	320	26	35 (88.9)
	325	26	25 (63.5)
	335	26	15 (38.1)
E110S (1/16-in. [1.5 mm] diameter) (argon with 2 percent oxygen addition)			
A 514	225	20	15 (38.1)
	280	20	15 (38.1)
	330	19	15 (38.1)
	370	18	15 (38.1)
	390	25	15 (38.1)
	425	24	15 (38.1)
	455	24	15 (38.1)
	465	24	15 (38.1)
	500	30	15 (38.1)
	120	15	15 (38.1)
	225	14	15 (38.1)
	245	14	15 (38.1)
	300	20	35 (88.9)
	300	20	25 (63.5)
	300	20	10 (25.4)

Table 4

Voltage Limits

Electrode	Voltage Limits, V
E6010	28 to 32
E6011	28 to 32
E6013	22 to 26
E7018	25 to 28
E7024	26 to 32
E8018	22 to 28
E11018	25 to 30

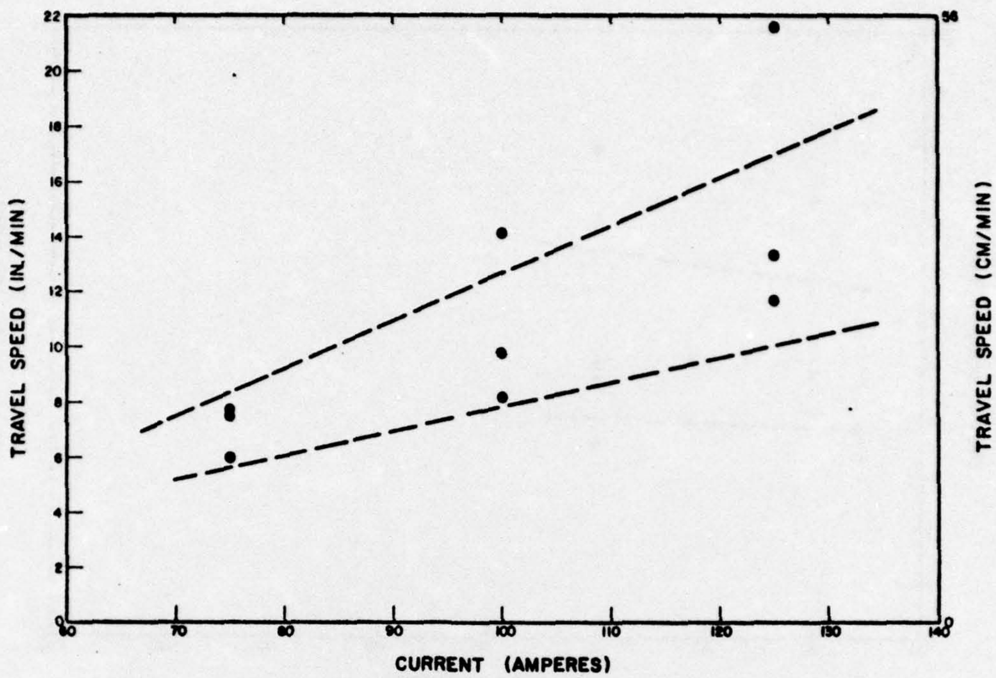

Figure 1. Graph of travel speed versus current for 1/8-in. (3.2 mm) diameter E6010 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

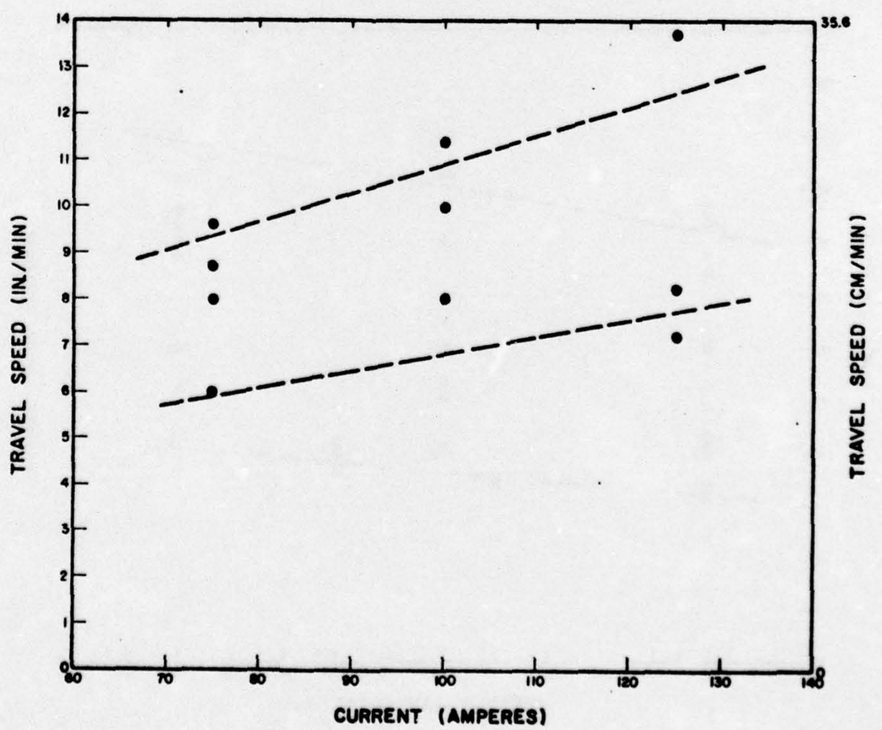

Figure 2. Graph of travel speed versus current for 1/8-in. (3.2 mm) diameter E6011 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

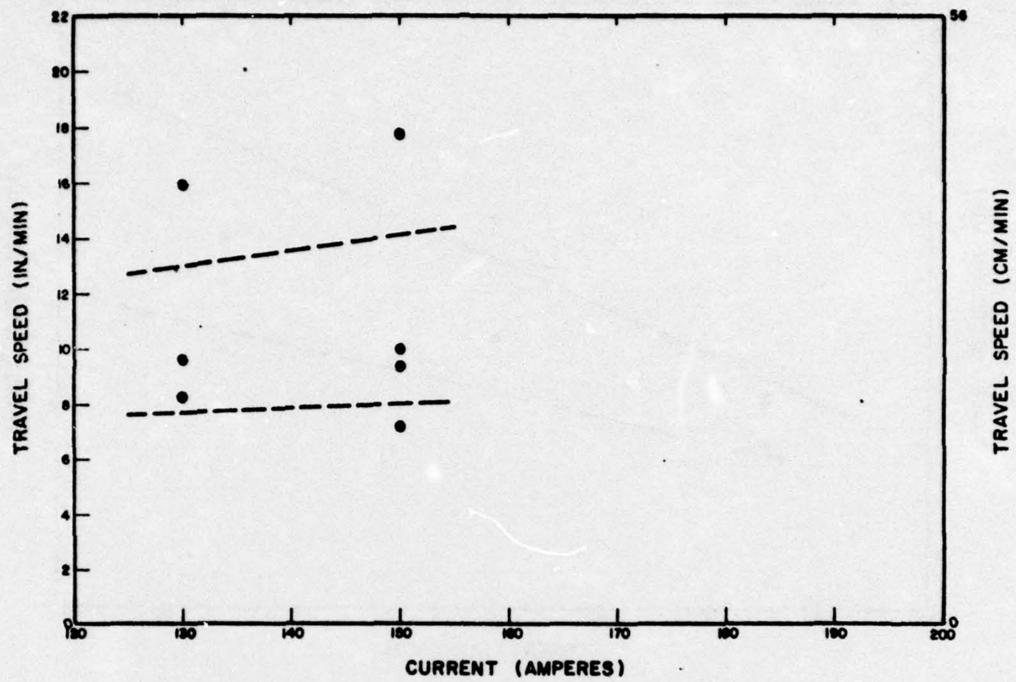

Figure 3. Graph of travel speed versus current for 1/8-in. (3.2 mm) diameter E6013 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

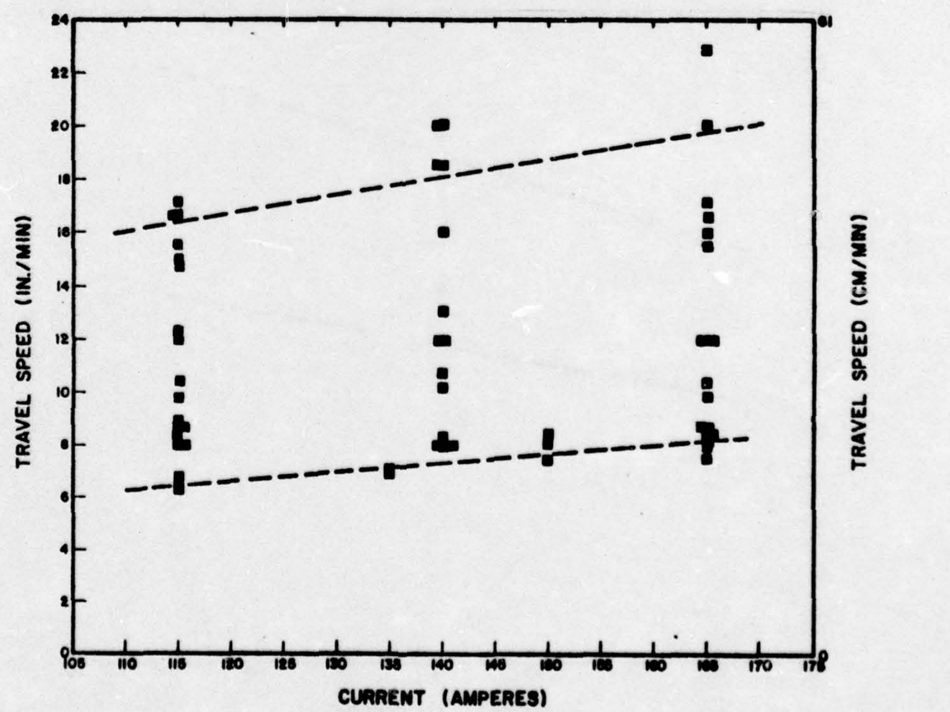

Figure 4. Graph of travel speed versus current for 1/8-in. (3.2 mm) diameter E7018 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

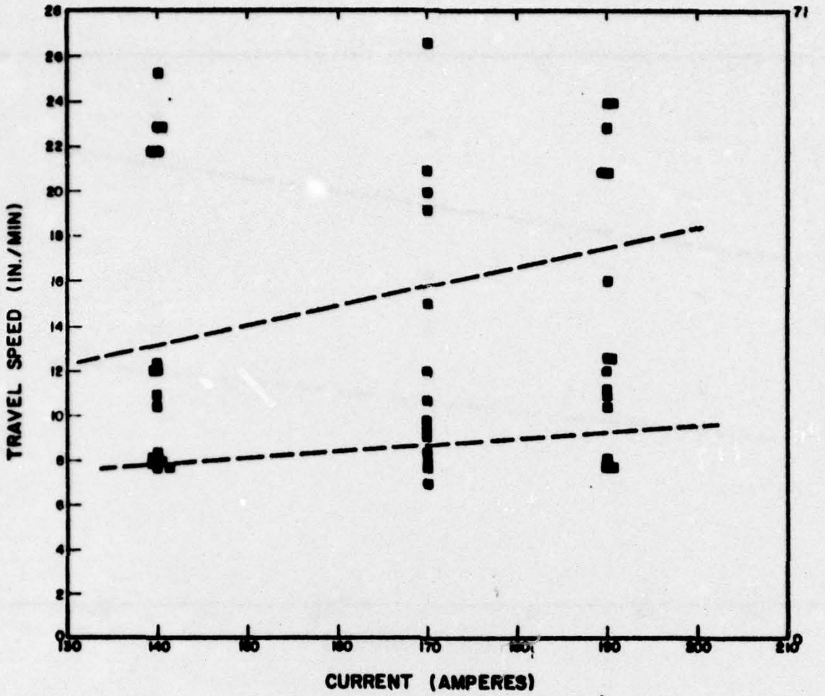

Figure 5. Graph of travel speed versus current for 1/8-in. (3.2 mm) diameter E7024 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

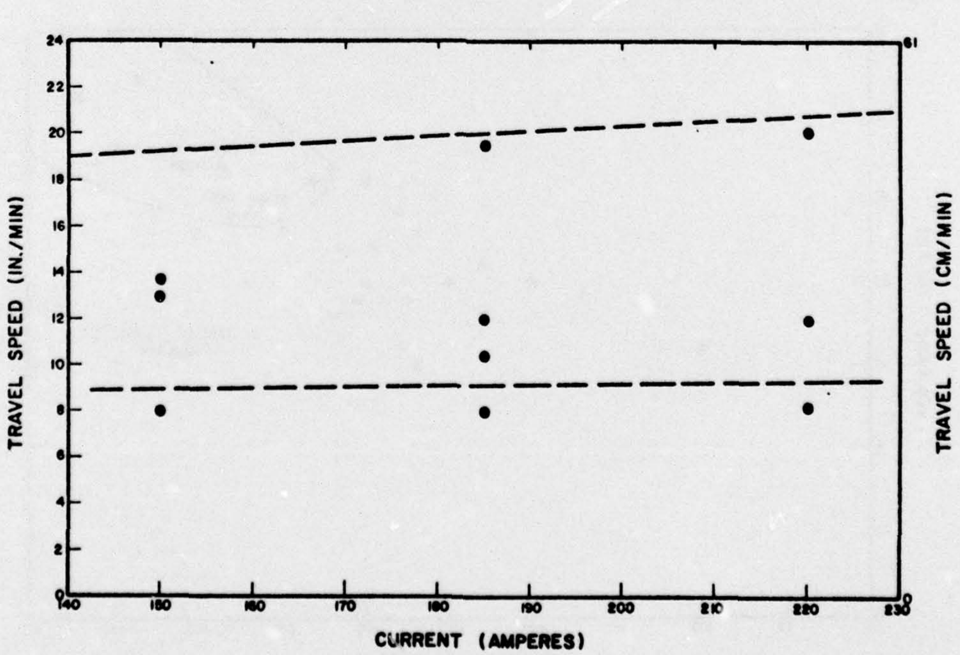

Figure 6. Graph of travel speed versus current for 5/32-in. (4.0 mm) diameter E8018 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

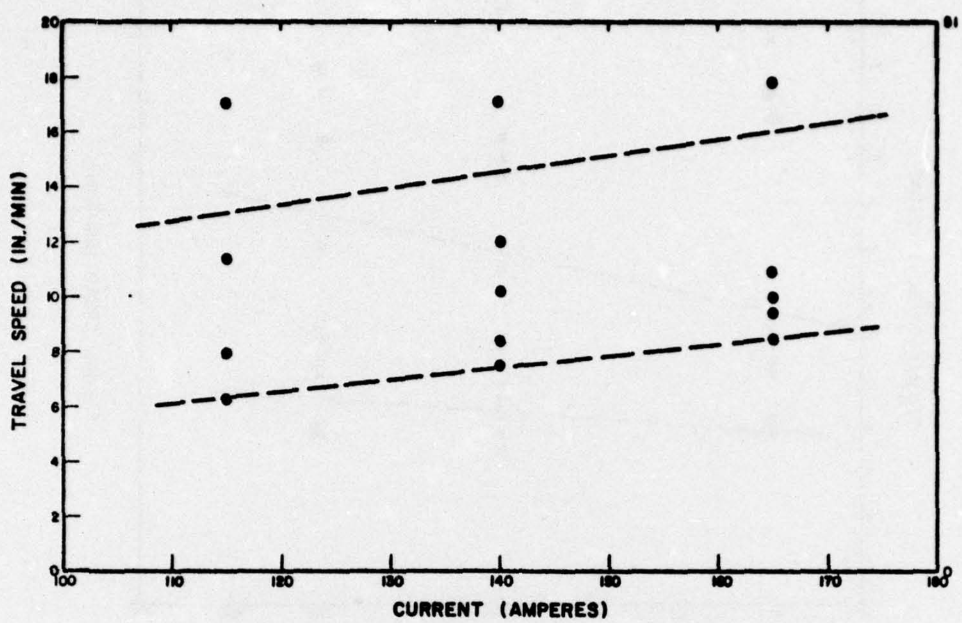

Figure 7. Graph of travel speed versus current for 1/8-in. (3.2 mm) diameter E11018 SMAW electrode. Dashed lines show travel speed limits as determined by amount of undercut and bead shape.

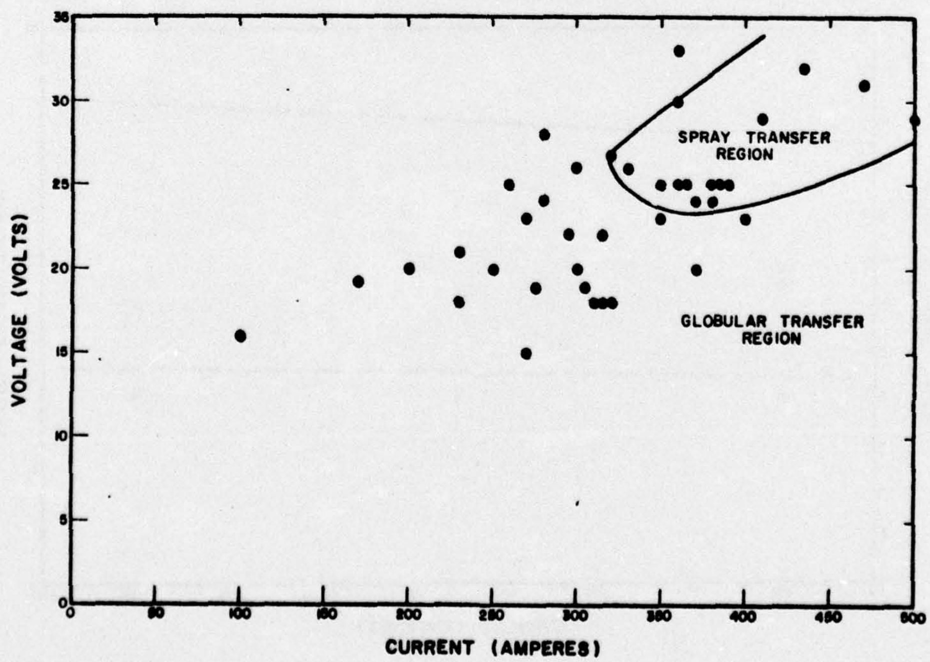

Figure 8. Graph of voltage versus current for E70S-2 electrode and shield gas of argon with 2 percent oxygen addition.

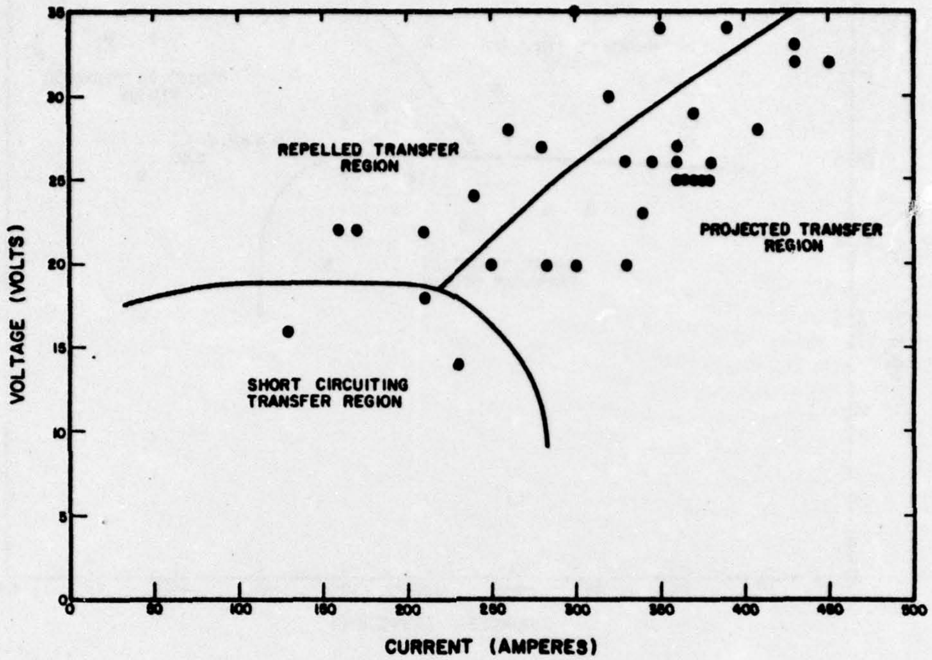

Figure 9. Graph of voltage versus current for E70S-2 electrode and carbon dioxide shield gas.

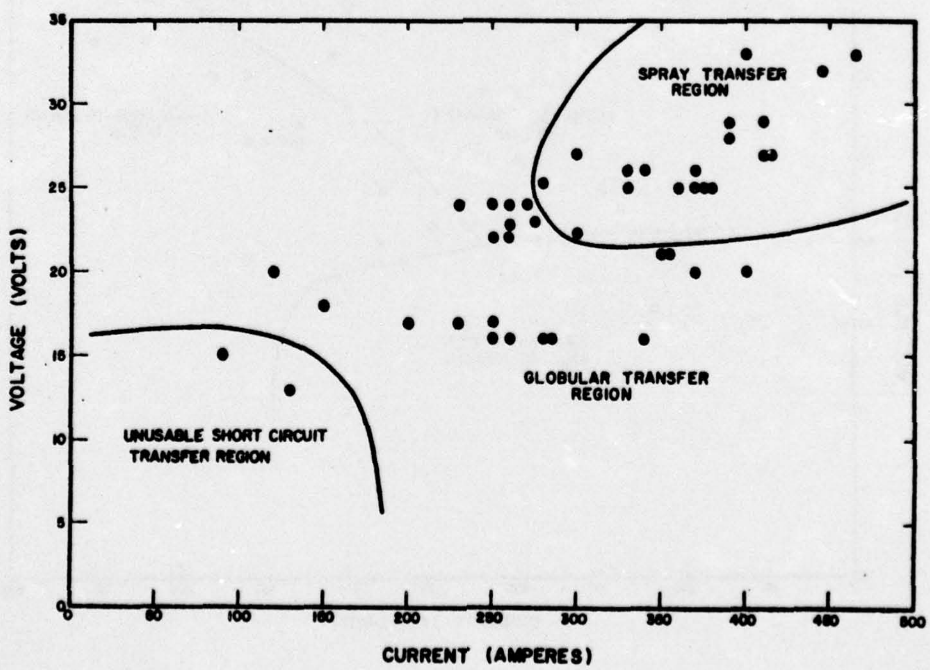

Figure 10. Graph of voltage versus current for E70S-3 electrode and shield gas of argon with 2 percent oxygen addition.

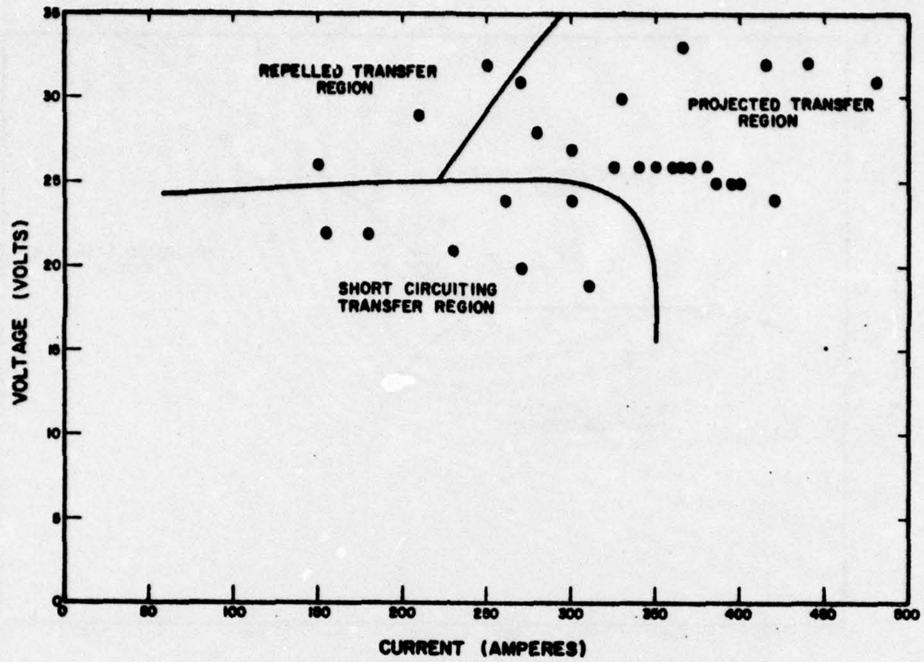

Figure 11. Graph of voltage versus current for E70S-3 electrode and carbon dioxide shield gas.

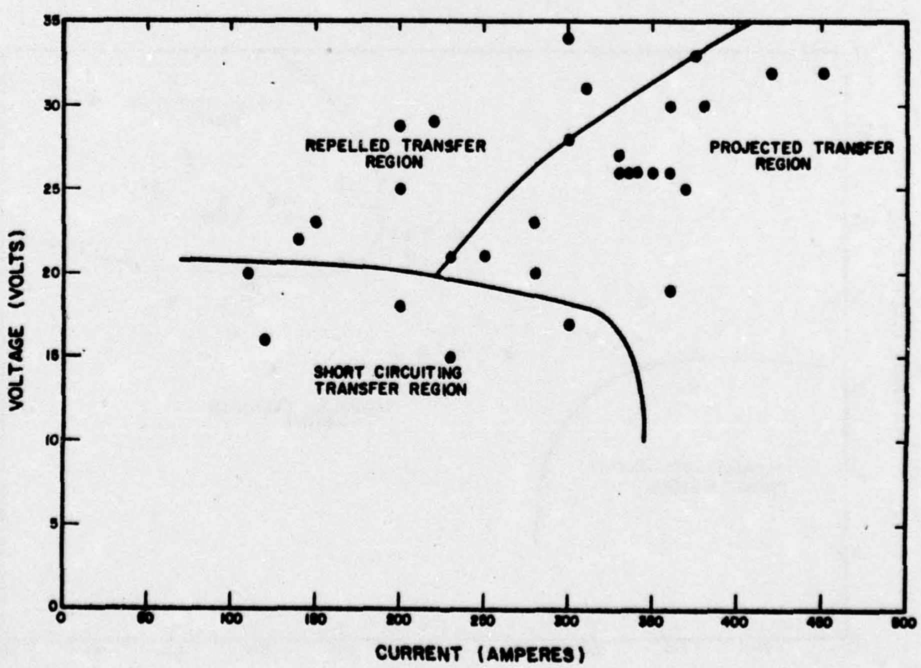

Figure 12. Graph of voltage versus current for E70S-4 electrode and carbon dioxide shield gas.

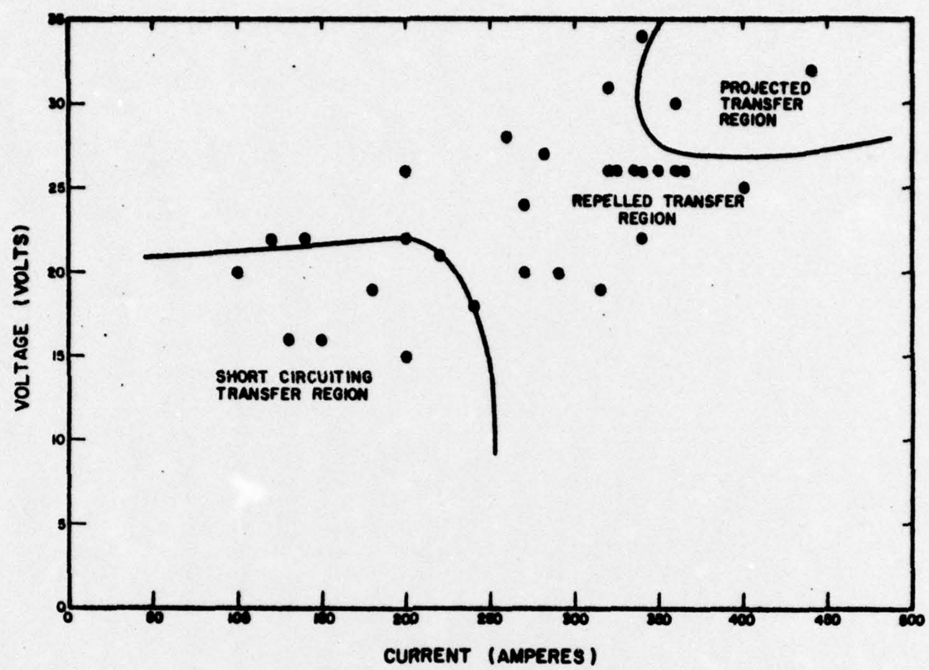

Figure 13. Graph of voltage versus current for E70S-6 electrode and carbon dioxide shield gas.

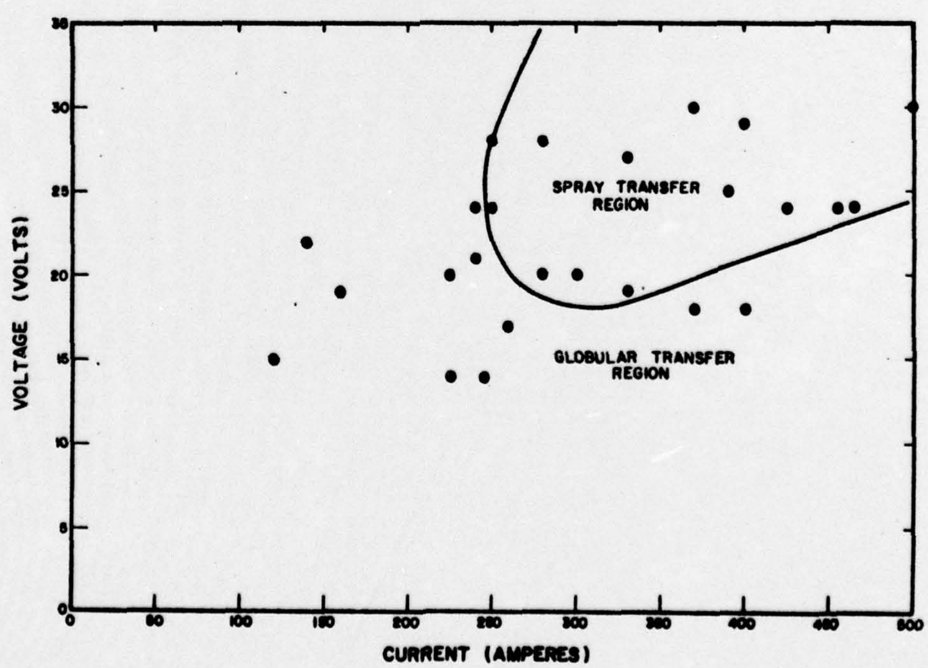

Figure 14. Graph of voltage versus current for E110S electrode and shield gas of argon with 2 percent oxygen addition.

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